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Properties of Planar Surface Wave Excited Plasma

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The properties of the planar surface wave plasma are discussed from the view point of electron heating in the plasma at the low pressure, referring to the experimental evidences. The role of the dielectric plate is considered. The plasma density profiles in the radial direction can be modified by controlling the microwave in the dielectric plate.

1. Introduction

The surface wave plasma in the cylindrical geometry has a long history of investigation originated from the 1970's. Extensive experimental and theoretical results obtained till now are summarized in the literatures [1]. Therefore, the present paper will be focused to the planar surface wave plasma, which was firstly reported in 1989 [2].

The planar surface wave plasmas have attracted an increasing interest in the industrial application since they can produce high-density plasmas with a large diameter at the low pressure without magnetic field. Many types of planar surface wave plasmas have been developed using several methods of the wave excitation to feed the microwave power at the top [3-4] or from the side wall [5] of the discharge chamber. The details of the planar surface plasmas have already been reported in the review paper [6]. From the view point of plasma physics, it is important to consider the mechanism of the energy transfer from microwave to electrons in such a low-pressure plasmas that the collisional electron heating is not effective: in other words, electron collision frequency is much lower than the microwave frequency. The present paper will report the experimental results related to electron heating mechanism measured at the low pressure argon in the planar surface wave plasma whose apparatus consists of a large diameter quartz plate and an annular slot antenna [4]. The role of the dielectric plate will also be discussed since some part of microwave can propagate inside the dielectric plate and interact with the plasma, which permit to modify the plasma profiles in the radial direction.

2. Experimental apparatus

The experiments were carried out in argon gas in a microwave planar plasma source. The apparatus used in the experiment has been taken into account to keep a good axial symmetry using an annular slot antenna as a surface wave launcher, for the sake of easier consideration of experimental results. The 2.45GHz microwave power of 0.2 - 2 kW is applied to produce the plasma to a cylindrical discharge chamber with 312 mm in diameter and 350 mm in height. The microwave couples to the chamber through a quartz plate with a thickness of 15 mm by an annular slot antenna backed by

a tunable cylindrical cavity [4]. The cylindrical tungsten Langmuir probes were moved along the chamber axis or rotated in the azimuthal direction to measure the plasma density and electron temperature profiles.

3. Experimental results and consideration

3.1 Hole on the axial probe current profile [7]

The axial profiles of the probe current are measured along the chamber axis as a function of the argon gas pressure, microwave power and the probe bias voltage. Figure 1 shows the typical example. The probe current rapidly increases from the quartz plate, taking a maximum at around 50 mm and then gradually decreases towards the bottom of the chamber. It is clearly shown that the hole appears on the probe current profile at a certain axial position of around 30 mm from the quartz plate and that the depth of the hole becomes small with

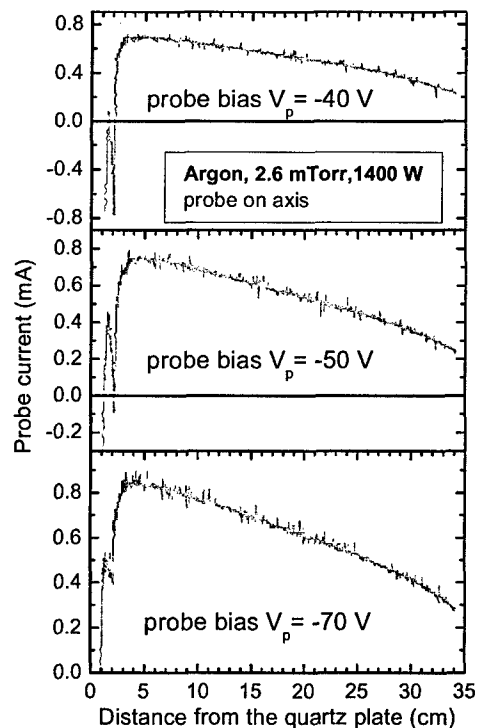


Fig. 1 Axial probe current profiles measured along the chamber axis in argon at 2.6 mTorr and absorbed microwave power of 1.4 kW for three different probe bias voltages.

decreasing the probe bias voltage from -40 V to -70 V, diminishing at -50 V. When the plasma potential of 20 V is taken into account, the energy of the hot electrons is estimated to be around 70 eV. It is interesting that the electron density at the hole always coincides with the cutoff plasma density ($7.4 \times 10^{16} \text{ m}^{-3}$) for the other experimental conditions. However, the hole does not appear in the probe current profiles when they are measured under the slot antenna. This suggests that the hole creation is responsible for the microwave electric field in the axial direction.

3.2 Hot electron measurement [8]

Another experimental evidence of electron heating in the low pressure surface wave plasma is an isotropic probe characteristics measured by the specially designed probe that the plasma particles can be collected from the specified direction, as shown in Fig.2(a). Figure 2(b) shows a set of the probe characteristics measured at 100 mm from the quartz plate by the collecting surface of the

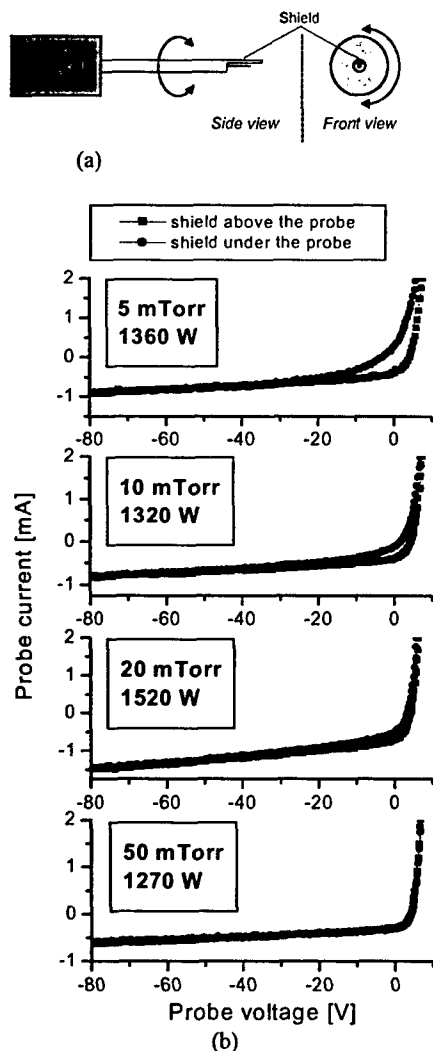


Fig.2 (a) One-side shielded Langmuir probe, (b) Probe characteristics measured at 100 mm under the quartz plate with the shield positioned above and under the probe tip.

probe facing to the quartz plate (the top of the chamber) and to the bottom of the chamber. Significant difference is observed in the region of bias voltage higher than -40 V at the low pressure and decreases with increasing the pressure. The differences come from the high energy electron flux directed away from the quartz plate, originated at the resonance region near the quartz plate as mentioned before. Assuming the hot electron energy of 60 eV, electron mean free paths estimated at the pressure of 5, 10, 20 and 50 mTorr are 306, 153, 76 and 31 mm respectively, which can explain the directed electron flux cease at higher pressure.

3.3 Active control of plasma density profile

A tuning system for a planar surface wave plasma source [9] has been developed, based on T-junction tuning element. It can control the plasma diameter, matching and radial plasma density profile since the microwave propagation inside the quartz plate is effectively controlled by the position of three plungers of T-junction tuning element.

3. Summary

Two experimental evidences of electron heating in the low-pressure surface wave plasma have been observed by the probe measurement. The heating region is close to the quartz plate where the plasma density coincides with the cut off plasma density.

The origin of localized hot electron can be explained on the basis of the heating mechanism proposed by Aliev et al [10]. The electrons entering the plasma resonance region where the microwave electric field is enhanced can take energy from the field if their transit time through the region is short compared to the field period. Otherwise, electrons cannot gain any energy from the field when averaged by one period of the field. The transit time estimated for hot electrons fulfill the necessary condition for transit time heating.

4. References

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